Patent draft

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Title

Clean-up filters made of tapered fibers

Abstract

This invention consist of making wavelength filters with prescribed spectral response by using 1 or more tapered fiber filters to match the spectral properties. The invention includes a method to decompose the desired response in basic elements which can be achieved by single tapered fiber filters.. The invention also indicates method to concatenate the tapered fiber filters to achieve the prescribed spectral response.

Field of the invention

The invention relates to making optical fiber filters by tapering the optical fiber at one or more place to produce a prescribed spectral response. This invention also relates to a method to decompose the prescribed fiber response in basic elements which can be achived by individual taper fiber filter, and a method to combine these filters to achieve the prescribed response.

Background of the invention

Tapered fiber filters are made by tapering a single-mode optical fiber in a way to produce an interference between cladding modes, which creates a transmission which is wavelength dependent. Such tapered fiber are well described in Canadian patent #1284282 and #31317495 and US patent # 4946250. The first patent referes to a way of combining tapered fiber filters to produce a bandpass filter whereas the two latter patents refers to a way to combine two tapered fiber to produce a passband/stopband filter. This patent is viewed as an improvement over both prior patents because it describes a way to design and combined tapered fiber filters to produce filters with almost any types of spectral response and has particular applications a clean-up filters, i.e., filters that are aimed to correct wavelength response of optical systems. In a simultaneous patent application, methods to make precise sinusoidal response with tapered fibers is described. This goal of this patent resides only in how to analyse a spectral response and extract the basic sine from the desired response, produce the desired fiber tapers and assemble them to obtain the desired response

Summary of the invention

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Preferred embodiement

A filter response, such as the one shown in Fig. 1, is analysed with a computer program that can automatically or manually simulate independent sine waves that take the form

$$T = \beta(1-\alpha \sin^2((\lambda-\lambda_0)\pi/\Lambda))$$

Where T is the optical transmission of the filter, α is the amplitude of the filter, β is the maximum transmission, λ is the wavelength, λ_0 is a reference wavelength or center wavelength of the filter, and Λ is the wavelength period. The program does the product of these function.

$$F = T_1 \times T_2 \times T_3 \times T_4 \times T_5 \ldots \times T_N$$

Where F is the resulting filter function of the concatenation of the tapers that have the transmission functions T_1 to T_N. Such numerical formula simulates the concatenation of the tapered fibers as shown in Fig. 2. This model suppose that the cladding mode between each taper are supressed. This can be physically achieved several ways : by leaving enough fiber length with the protective jacket on and by bending the fiber, by making tapers that are single-moded, by strongly bending the fiber, etc.

The parameter of the similation are the four parameters of each sine function α_1, β_1, ,λ_1, Λ_1, ..., α_N,λ_N,Λ_N. These parameter are adjusted manually or with the aid of a computer program to simulate with the smallest deviation from the desired response as shown in Fig. 3. The number of tapers needed may vary with the desired shape. In this example 4 tapers are used to model the desired profile within 0.25 dB. The mathematical method used was base on a minimization of the square of the difference between the model and the desired filter response, but other methods can be used or developped. It is important to note that these decompositions to achieve a given filter response within a given margin are not unique. The idea thus becomes to select a solution the is the easiest the manufacture. The design becomes thus related to the control on the manufacturing process. On good example is given in this embodiement.

Thus, after determining the parameters of the individual tapers, one can realize each individual component. For that one must, in the fabrication process, be able to control those parameters.

Realization of Sinusoidal tapered fibers filters

When tapering a single-mode fiber, as shown in fig. 4a, the taper slope will be controlled by the size of the heat source used and the pulling speed. Using a small flame will cause an abrupt slope to be formed which will usually coupled more than two modes, creating modulated sine response as shows in patent 1284282. However, This modulated sine response is problematic in the model because it involves the control of a lot more parameters, i.e., the amplitude of each mode and their respective phases.

To avoid this problem we have developped methods to produce tapers with two-moded sinusoidal response where the amplitude period and phase are controlled. The general method is described in the patent application#.... With a taper profile schematized in Fig. 4b), one can achieve almost any sine response. However, in the particular case that only the amplitude of the sine function is less approximately 50%, the simpler profile of figure 4a can be used to produce the tapered fiber filter.

Because the undersired three and higher order modes are caused by a taper slope that is to large, one can reduce this effect by reducing the slope. Thus one can modify the spectral response if one increases the brush width from 0 to a few mm. One will see the total amplitude and the amplitude of the modulations decrease. If the total amplitude is limited to 50%, the modulation is reduced to a few percent, making this response almost perfectly sinusoidal. If the brush width is still a bit wider, the modulation completely disappears. At 20% total amplitude, no extra modulation is observed. As in the patent 1284282, the wavelength period is then controlled by the length of the taper, i.e., the number of oscillations in the elongation. The control of the length enable the realisation of spectral responses with periods from 400 to a few nm.

In both the taper fabrication cases described above, once a taper is fabricated and the desired shape is realized, the taper is bonded to a substrat and packaged in a steel tube for protection.

Each taper can be done individually and spliced with the other components or they can be made in succession on the same fiber.

Figure 5 shows the realised taper responses compared with the model. In this design, it is important to note that the 3 small amplitude tapers were done first using the simple profile shown in figure 4a. The last taper with 4 dB amplitude was made using the general method resolting in a profile similar to figure 4B. Because the method gives a lot of flexibility, the parameters were adjusted to compensate of the errors is the first three tapers. The fourth taper was made directly in line with the three first taper and its response was adjusted to best matched the total response and the desired filter response. The error between the experimental response and the desired filter response is approximately 0.4 dB.

Of course, a greater control of the taper performance is desirable. This will also permit the realisation of more complexe taper response, such as modulated sine response, which may be used as new tools in the decomposition of the desired filter response, enabling the reduction of the number of taper structures needed, or better matching of the response.